

SINKING TO NEW LOWS & RISING TO NEW HEIGHTS: THE TOPOGRAPHY OF EUROPA.

Paul M. Schenk, Lunar and Planetary Institute, Houston, TX 77058 (schenk@lpi.usra.edu).

"Neither can the weak ice support high mountains. Topography is at most a few hundred meters high."

Introduction: The perception of a "flat" Europa dates to Voyager days, when terminator images showed little relief except ridges and a few knobs [1]. While ridges rarely exceed such heights, Galileo has shown that topography on longer scales (kilometers to 100's of km) is decidedly variable. Topographic measurements of selected features have been reported [e.g., 2-4] but no systematic description or appraisal of Europa's topography has been attempted, until now.

Topography of a planet is one of its most fundamental characteristics (witness the Mars revolution wrought by MOLA), and is a direct expression of the response of the lithosphere to external and internal forces. The resulting topographic expression is in turn directly related to the properties of that lithosphere, and this is especially true in the case of a floating ice shell.

Tools: Tools for the production of 2-dimensional topographic maps (DEM's) are stereogrammetry (3D) and 2-D photogrammetry (PC). These tools have been described elsewhere [e.g., 4]: here I focus on the advantages and limitations of each technique. Stereo DEMs can be treated as rigid plates, except for linear mosaics where "bending" of the mosaic and resulting DEM can occur if image registration is not done with care. As there is no global topographic net for Europa tied to the center of mass, all DEM's "float" with respect to the true surface, but a reasonable approximation to the true tilt can be had by proper image registration. Stereo DEM registration is also limited to no better than 3 times worse than the lowest resolution image in the stereo pair. PC can achieve full pixel DEM resolution but accumulated errors and uncertainties degrade the reliability of measurements at length-scales of more than 50 pixels or so. Use of low-phase angle images to model local albedo partially reduces this problem. We are fortunate that on Europa many PC sites are coincident with stereo coverage, which I use to control long-wavelength deviations in the PC, while preserving high-resolution fidelity.

Topographic mapping coverage is highly vari-

able in quality and decidedly limited (perhaps the most significant loss due to the LGA failure). Vertical precision ranging from 5 to 50 meters. Stereo coverage, including untargeted stereo pairs, is available for <2% of the surface (except for low resolution coverage of ~15%). PC mapping is more extensive (~20%), with pixel resolution ranging from 10 m to 1.4 km.

Often only one or two examples of a geologic feature or terrain type are available. Thus the observed properties of one example may not necessarily be representative of all such features. Even when we can characterize a given feature, because imaging coverage is so limited, topographic mapping often does not extend far from the target features. Knowledge of the regional topographic characteristics can be very important for the interpretation of some features, and these limitations must be acknowledged.

Focus on the Dark Spot: A few features on Europa were targeted for multiple observations, allowing for detailed topographic mapping at various scales. One of these, Castalia Macula (aka., The Dark Spot) is revealed as a broad depression 350 m deep [5], sandwiched between two large domical rises, the largest of which is fault-bounded and rises a whopping 900 m, for total relief of 1250 m. Dark material is mostly confined to this depression, although some patches lie on the domes. Remnant ridges are preserved on the dark floor, such that if due to volcanism, dark material burial was not deep.

Other negative topographic expressions include pits typically 10-20 km across, and up to 400 m deep. Irregular and curved troughs can be 500 m deep (and in one case >1 km deep! These may constrain the shell to no less than 6 km thickness [6].

Focus on Chaos: Conamara is by far the best studied site on Europa. Stereo coverage of Conamara is possible at 4 different scales: 180 m (regional), 180 m (medium-resolution swath), 55m, and 9 m. Low-sun PC topography is coincident with the first 3 of these, providing controlled full resolution pixel-scale mapping of all Conamara at 180 m, and selected higher resolution patches of the interior.

The matrix component of Conamara Chaos is

generally elevated 200-300 m above surrounding plains, but is also variable by a similar amount [7]. Highest elevations are correlated with areas dominated by matrix. Locally, older blocks can be 200-300 m high (effectively doubling block thickness estimates [2]). Some blocks, however, are lower than matrix only a few km away, suggesting that matrix was rather viscous as blocks were rotated.

Several other chaos sites were observed in stereo. Some chaos units are elevated above surrounding terrains, others are not, suggesting that chaos evolution is complex or can respond to post emplacement modification. Lenticulae (oval chaos-textured domes) also appear to be variable in elevation. Several have been observed in excess of 150 m local relief, placing tight constraints on convection dynamics [8]. Others have no positive topographic expression. In several instances, moats form within chaos or lenticulae along their border with ridged plains. Although elevated and variable relief for chaos and lenticulae tends to favor a diapiric origin [7], these data provide key constraints for any model of chaos origin.

Having an Impact: Impact crater morphology is discussed in detail elsewhere, but the few large impact craters identified are important as they penetrate deeply into the shell. Initial and subsequent Galileo observations [2, 11] show that most craters <8 km across are similar to Ganymede craters, but that larger craters are shallower. The observed changes in morphology suggest that larger craters are penetrating into unusually soft material, and may sense the ocean. Inferred depths to the ocean are on the order of 20 km [2]. High resolution topography (vertical precision ~15 m) is available only for Manannan. Here, mappable melt deposits are correlated with isolated depressions, but most of the floor is rugged and probably comprised of uplift disrupted crust.

Learning to Relax: The icy shell also responds to vertical or horizontal stresses. Evidence for folding has been found at a few locations [9], but limited topographic coverage prevents a global search. However, stereo mapping several of these sites indicates amplitudes of 200-300 meters. One site reaches at least 1 km amplitude but its origin as folding is uncertain. These broad undulations are difficult to characterize with current data.

Evidence for flexure due to surface loads is found at double ridges [e.g., 10]. Using bent-plate models, the shape of the bending can be used to constrain elastic plate thickness. Flexure associated with an elevated rise has also been suggested near the crater Cilix [3]. Analysis of the topographic form suggests a thick shell, but the lack of regional topographic mapping precludes confirmation that this is truly flexure and not regional warping. Ridge and band topography will also be examined.

Regional Characteristics: Of 15 stereo sites analyzed to date, only 4 have total relief of less than 500 meters. None of these sites are greater than 300 km across, however. Larger areas can be mapped using PC but the long-wavelength characteristics are not reliable, and global coverage is incomplete. Nonetheless, provinces of distinct topographic characteristics are obvious. Mottled terrain is the most rugged. Ridged plains have variable relief but at longer wavelengths, with pits and domes predominating in some areas, absent in others. These patterns suggest that internal dynamics within the shell has strong regional control.

Despite the limitations, the topographic variability of Europa is much greater than expected, and the total dynamic range may approach 2 km. Large vertical fault movements of 300-500 m (and as high as 900m) are also not uncommon. The impression is of a lithosphere that is able to support large variations in topography, at least as great as those on Ganymede. These variations in relief are not consistent with a shell only a few kilometers thick, but more analyses are required to quantify this conclusion with confidence.

References: [1] Lucchitta, B., and L. Soderblom, in *Satellites of Jupiter*, 1982. [2] Williams, K., and R. Greeley, *GRL*, 25, 4273, 1998. [3] Nimmo, F., B. Giese, and R. Pappalardo, *GRL*, 29, 5, 1233, 2003. [4] Schenk, *Nature*, 417, 41, 2002. [5] Prockter, L., and P. Schenk, manuscript in preparation. [6] Schenk, P., and W. McKinnon, *LPSC XXXIII*, 2002. [7] Schenk, P., and R. Pappalardo, *Jupiter Conf. (abstract)*, 2001. [8] Showman, A., and L. Han, *LPSC XXIV*, 2003. [9] Prockter, L., and R. Pappalardo, *Science*, 289, 941, 2000. [10] Billing, S., and S. Kattenhorn, *LPSC XXXIII*, 2002. [11] Moore, J., et al., *Icarus*, 151, 93, 2001.